

Quasi-Biennial Oscillation Signatures in Ozone and Temperature Profiles Measured by the JPL Lidar at Mauna Loa

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INTRODUCTION

The stratospheric quasi-biennial oscillation (QBO) is most easily identified as an alternation of descending westerly and easterly wind regimes in the equatorial lower stratosphere [e.g., Reed *et al.*, 1961] with a period varying from 22 to 34 months. To attempt to elucidate the exact mechanisms of the equatorial and extratropical QBO, and because the QBO has a major impact on the interannual variability of the stratosphere and in turn on major issues such as ozone depletion and climate change, it is critical to maintain low-, mid-, and high-latitude continuous long-term measurements of the key atmospheric parameters. As part of the Network for the Detection of Stratospheric Change (NDSC), a Jet Propulsion Laboratory (JPL) lidar has been taking long-term measurements of middle atmospheric temperature and ozone at Mauna Loa Observatory, Hawaii (MLO, 19.5°N, 155.5°W), since 1993 [McDermid *et al.*, 1995]. The first simultaneous observations of the vertical structure (20–50 km) of the temperature and ozone QBO at a subtropical station are presented here.

LIDAR DATA SET

The data presented here extend from June 1, 1994, to September 30, 2000. The corresponding ~800 individual ozone and temperature profiles were computed into monthly means between June 1994 and September 2000. Then the climatological means were calculated for the period October 1994–September 2000 for each month of the year, thus covering three full QBO cycles. These climatological monthly means were subtracted from the individual monthly means to obtain what is hereafter called the "deseasonalized" ozone and temperature profiles. The seasonal (mainly annual and semiannual) components were removed, leaving the possible signatures of the QBO, solar cycle, long-term trend, and any other interannual variations. Because of the relatively short measurement period, no attempt was made to isolate each of these interannual components.

QBO WINDS

A comparison of the NOAA/National Weather Service (NWS)-Hilo monthly mean zonal winds near 30-km altitude with the near-equatorial monthly mean zonal winds at 10 hPa (~30–31 km) shows a clear in-phase correlation, indicating that Hawaii is under the influence of the equatorial QBO winds. The 2D time-height section of the zonal winds at Hilo is shown in Figure 1 (bottom panel). In this panel the altitude range extends from 15 to 35 km, but the scale of the vertical axis has been chosen to match that of the ozone and temperature plots displayed above it. The contours range

from -10 (violet) to $+10$ m s^{-1} (red) with a 1 m s^{-1} interval. The QBO structure is well identified and is therefore used as the QBO wind reference to investigate the phases of the temperature and ozone QBO signatures in the next sections.

QBO SIGNATURES IN THE TEMPERATURE PROFILES

The 2D time-height section of the deseasonalized stratospheric temperatures is shown in Figure 1 (top panel). No QBO signature was identified above 60 km. The contours range from -3 (violet) to $+3\%$ (red) with a 0.5% interval. The most striking feature observed here is a clear seasonally synchronized QBO anomaly near 35–36 km in winter with an amplitude exceeding 3% (6–7 K). The warm phase coincides with the maximum westerlies at 30 km, i.e., with an expected easterly shear above 30 km. The cold phase coincides with the maximum easterlies at 30 km, i.e., with an expected westerly shear above 30 km.

QBO SIGNATURES IN THE OZONE PROFILES

The center panel of Figure 1 shows the 2D time-height section of the deseasonalized ozone profiles. The plot is divided into two parts. The lower part (between 20 and 30 km) shows the deseasonalized ozone number density (in %), with contours ranging from -12 (violet) to $+12\%$ (red) with a 2% interval. The upper part (above 30 km) shows the deseasonalized ozone mixing ratio, with contours ranging from -0.5 (violet) to $+0.5$ ppmv (red) with a 0.1 ppmv interval. Although the lidar measures ozone number density, the mixing ratio is preferred for display above 30 km to avoid excessive percentage values in the upper regions where the ozone number density is very low. No ozone number density contour is displayed below 20 km because of the large relative variability in the lower stratosphere ($\pm 100\%$). Note that since relative quantities are considered, the contours of the ozone mixing ratios and number densities above and below 30 km should, and do, exhibit very consistent structures. As was the case for temperature, a strong seasonally synchronized QBO signature can be observed in winter-spring with an amplitude exceeding 0.5 ppmv (10%) near 31 km.

DISCUSSION

This first investigation of simultaneous temperature and ozone QBO signatures at Mauna Loa, Hawaii, has revealed a remarkably consistent pattern, typical of the expected extratropical asymmetrical effect of the stratospheric QBO. Although less organized and weaker (10 – 15 m s^{-1}), the observed QBO winds from NOAA/NWS in Hilo, Hawaii, are in phase with the equatorial QBO winds. The temperature and ozone results obtained by the JPL ozone lidar show a clear

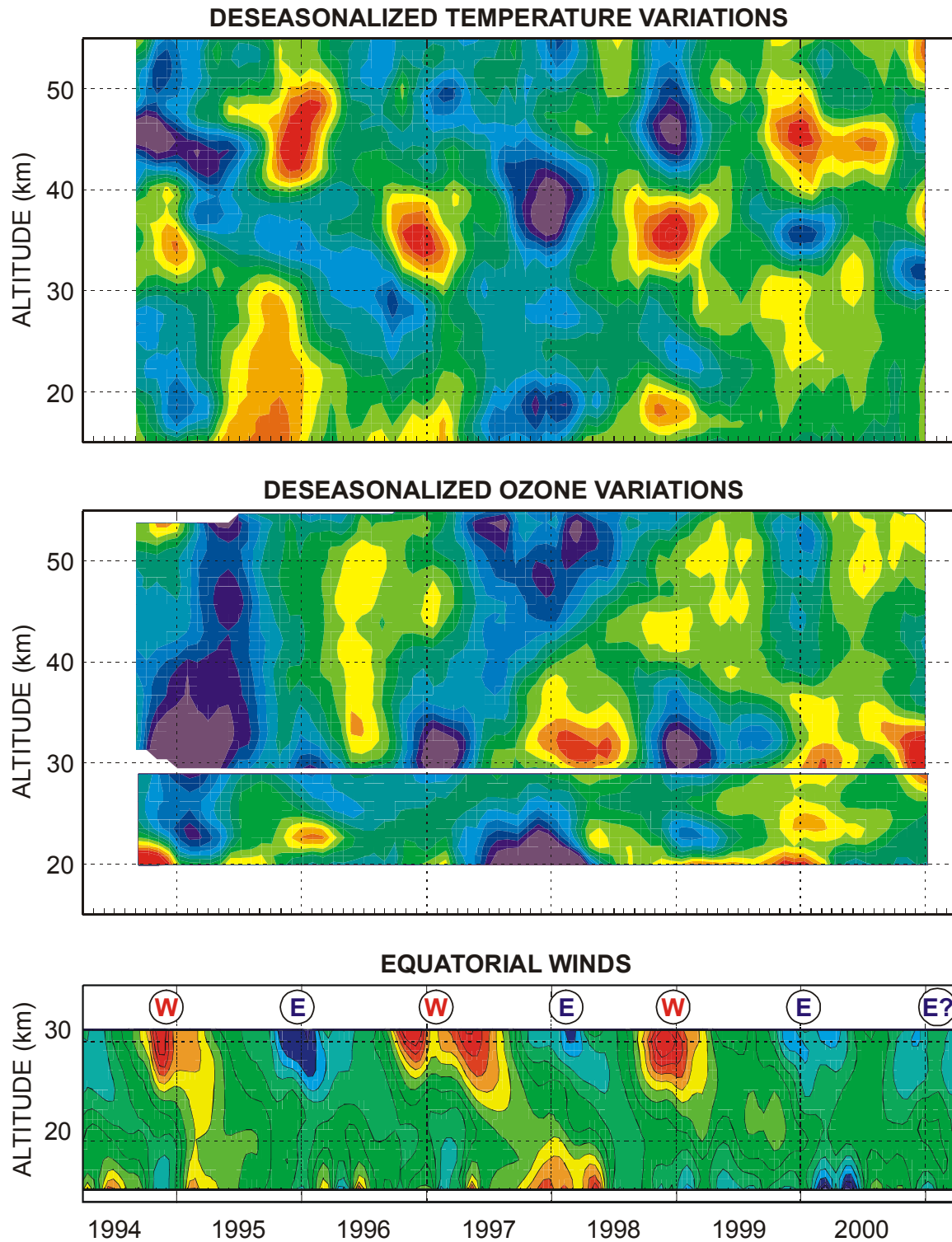


Fig. 1. Two-dimensional time-height sections of the deseasonalized temperature (top), ozone (center), and winds (bottom). Top: The temperature contours range from -3 (violet) to $+3\%$ (red) with a 0.5% interval. Center: For ozone, the lower part (between 20 and 30 km) shows the ozone number density (in %), with contours ranging from -12 (violet) to $+12\%$ (red) with a 2% interval; the upper part (above 30 km) shows the ozone mixing ratio with contours ranging from -0.5 (violet) to $+0.5$ ppmv (red) with a 0.1 ppmv interval. Bottom: For the monthly mean winds at Hilo, Hawaii, contours range from -10 (violet) to $+10$ m s^{-1} (red) with a 1 m s^{-1} interval.

QBO signature at several altitudes and times of year, highly consistent with previous observations [e.g., *Randel and Wu*, 1996] and with the mechanisms suggested by modelers.

Both the prevalent temperature and ozone QBO anomalies are seasonally synchronized (northern hemisphere winter) and out of phase with the expected equatorial anomalies, indicating that Hawaii is located in the subtropical branch of the asymmetrical QBO-induced meridional circulation. The QBO-related temperature perturbations observed at Hawaii are clearly out of phase with those expected from thermal-wind balance at the equator, i.e., positive (hot) at 47 and 24 km, and negative (cold) at 35 km for easterly winds maximizing at 30 km. The QBO-related ozone perturbations appear to match remarkably well with those observed, for example, by the Stratospheric Aerosol and Gas Experiment (SAGE II) [*Randel and Cobb*, 1994; *Randel and Wu*, 1996], and simulated by *Jones et al.* [1998]: positive slightly above and below the altitude of easterlies (31 and 23 km, respectively, for easterlies maximizing just below 30 km) and a negative perturbation well above (>45 km). A weak signal has also been observed at 24 km in summer that appears to match the model results of *Jones et al.* [1998], but this signal is not consistent enough from year to year to be certain of its actual existence.

These results suggest that the mechanisms for production of the ozone QBO are more complex than that for temperature. Above the ozone concentration peak, the ozone QBO is both chemically and dynamically produced through the combined effect of the QBO nonlinear horizontal and vertical advection of NO_x and the horizontal advection of ozone. Below the ozone concentration peak, the ozone QBO is dynamically produced by nonlinear advection of ozone out of and into the neighboring latitudes. For temperature, the thermal wind balance causes the QBO signature in the subtropics to be out of phase with that at the equator. The warm phase in Hawaii coincides with the maximum easterly shear at the equator. The cold phase in Hawaii coincides with the maximum westerly shear at the equator.

A strong El Niño event in 1997-1998 considerably disturbed the QBO signature in both ozone and temperature. Its main effect was to reduce the lower stratospheric ozone

amount, and to cool down the lower stratosphere up to 25-27 km. Both El Niño/Southern Oscillation (ENSO) signatures in ozone and temperature are consistent with previous observations [*Shiotani*, 1992; *Randel and Cobb*, 1994; *Randel et al.*, 2000]. Despite this disruptive event, and even though the ozone/temperature lidar data set covers only three full QBO cycles, the results presented here have shown several significant QBO signatures and remain promising for a more detailed investigation of the temperature and ozone interannual variability at this latitude.

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